

Figure 1. Wisconsin Soil Moisture Study Sites

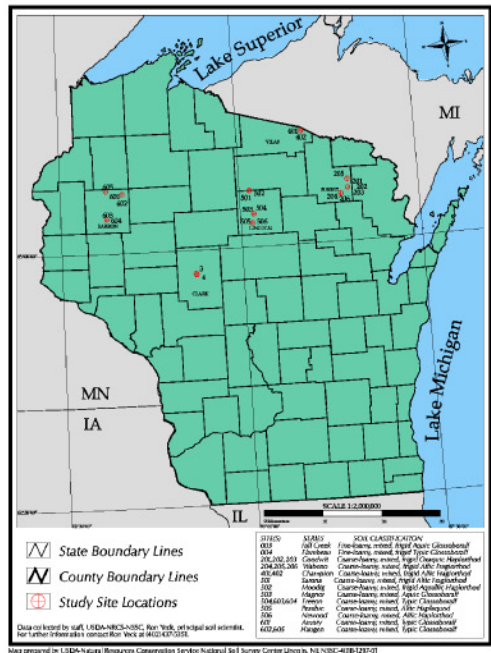


Figure 2. Soil Moisture Response to Rain

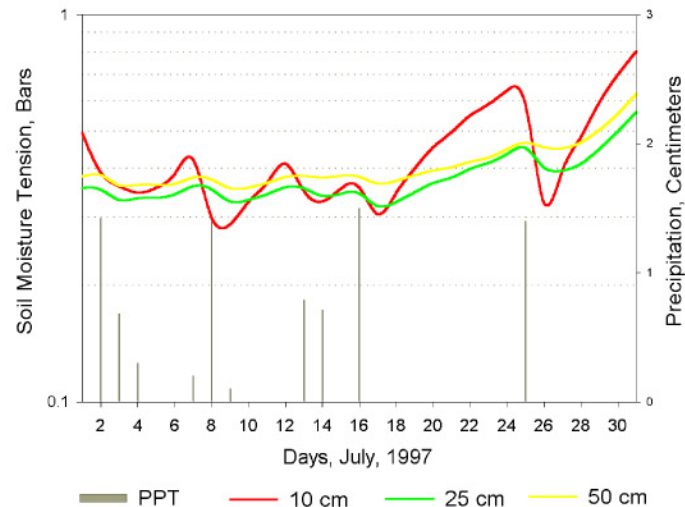


Figure 3. Detailed Soil Moisture Pattern -- "Automated"

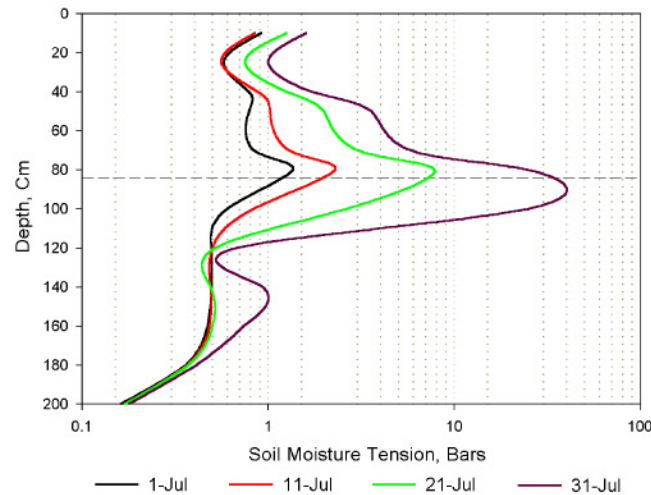


Figure 4. Monthly Soil Moisture Pattern -- "Automated"

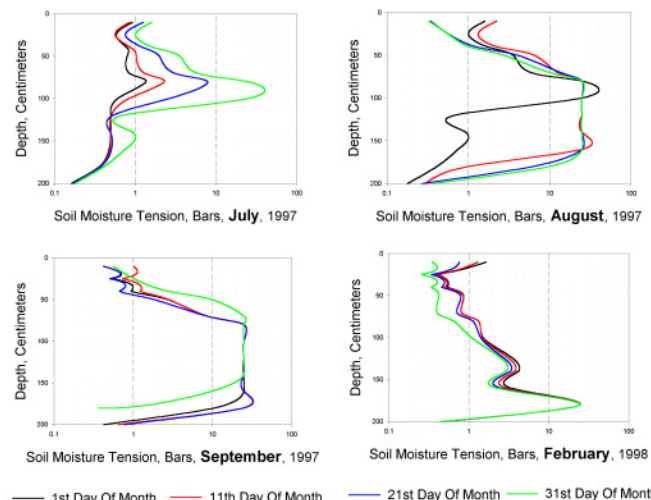
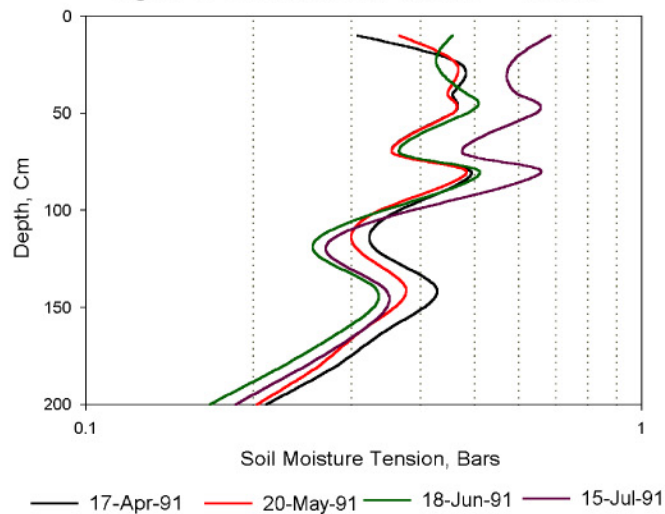


Figure 5. Soil Moisture Patterns -- "Manual"



Introduction

In 1990, we began installing a basic set of sensors that were manually read with an ohm meter one to three times per month. As funds and new technologies became available, dataloggers and other sensors were installed. The first dataloggers were installed in 1995 and the 1997 installations completed the site upgrades. The dataloggers are programmed to store two-hour averaged sensor readings. This poster discusses several benefits of automating the data collection and compares the annual site costs before and after their installation (Tables 1,2).

We compare the data applications and interpretations before and after automation and discuss those possible only with automation and those that are comparable regardless of automation.

Sensors and Data Collection

Manual Data Collection (Initial Installations)

At each site, resistance-type soil moisture sensors were installed at twelve depths (10, 25, 40, 50, 70, 80, 100, 120, 140, 180, and 200 cm) in triplicate. At most sites, combination sensors for both soil moisture and temperature were installed at three depths (25, 50, and 200 cm). Two sites have combination sensors at all twelve depths. Sensor leads were attached to rotary switches housed in PVC units. The PVC installations and data collection are shown in Photos 1 and 2, respectively. The sensors were commonly read two or three times a month during the growing season and once a month when soil was frozen and plants were dormant.

Automated Data Collection

Automated data collection was accomplished by installing dataloggers and auxiliary equipment. D-cell battery packs proved unreliable and were soon replaced with solar-charged batteries which provide a very reliable, trouble-free power source. Later, air temperature sensors were added. At some sites, piezometers (with automated water-level sensors) were also added. Photo 3 shows an automated site with a solar panel, an air temperature sensor, and piezometers. Data are downloaded four times a year from data storage modules. Photo 4 shows data collection with a laptop computer. The laptop computers have been replaced with the more convenient palmtop computers. Within a year, plans are to collect data by interchanging data cards instead of downloading data at the site.

The Case for Automating Soil Moisture and Temperature Monitoring

R.D. Yeck, D.J. Hvizdak, D.S. Harms, and R.F. Paetzold; USDA, Lincoln, Nebraska, and Spooner, Wisconsin

Discussion

For brevity, data collected with the meter will be referred to as "manual" data and data collected using the datalogger will be referred to as "automated" data.

Soil Moisture

Figures 2 through 5 depict soil moisture data applications. Figures 2 through 4 are from the "automated" data and Figure 5 is from the "manual" data.

Figure 2 shows the response of soil moisture tension to precipitation. The soil moisture tension response time is detectable only with data collected at close intervals. At the 10-cm depth, the soil moisture tension decreases almost immediately after the rain; whereas the soil moisture tension at 25 cm did not change noticeably until the fifth day when the cumulative rainfall was 4 cm. We could also determine responses as frequently as every two hours. This is the only site that has hourly rainfall data available and provides incentive to install rain gauges at several other sites.

Figure 3 depicts soil moisture tension changes in July of 1997. These data show response to rain in the upper 20 cm but the moisture tension is dominated below 20 cm by moisture removal by roots and by the upper boundary of the dense till material (described at 84 cm in the pedon description). The bulk density of the dense till in this pedon is 1.8 g/cc.

Figure 4 shows the soil moisture tension patterns with depth for July through August and for February when the soil again becomes more moist.

Figure 5 shows 1995 "manual" data for the same site. It represents a 4-month time period and is the most detailed data available for those months. This graph shows generalized data that are useful, but limited, because more detailed soil moisture data are not available during this active plant growth period.

Whereas the data represented by Figure 5 is generalized at similar time-intervals as the data in Figures 3 and 4 and provides similar data, no more detailed time-interval interpretations are possible using the source data for Figure 5. However, the "automated" source data used for Figures 3 and 4 allows the option to summarize the soil moisture changes at closer intervals, even every two hours, if desired.

Soil Temperature

Table 4 compares the "automated" and "manual" soil temperatures for a Forest County site for 1998. The 1998 dates used to calculate "manual" averages were those for which data were read by meter in 1995 prior to installation of the dataloggers, and thus are simulated "manual" readings. To have valid comparisons of the temperature averages, data needed to be from the same year. For the data shown in this table, only the mean annual temperature differed by more than 1°C between the "automated" (2-hour intervals) and the "manual" data (collected no more than three times per month). The mean winter averages varied no more than 0.2°C and the mean summer temperature by a maximum of 0.6°C. Although the results could be different for other years and locations, these data would indicate that at least mean winter temperatures could be determined with only one or two measurements per month.

Figures 6 and 7 are from "automated" data and Figure 8 is from the "manual" data. Figure 6 depicts the period of soil temperatures that also defines the "dynamic soil moisture period" when the soil is not frozen and when plants are growing. The detail of Figure 6 indicates that the soil temperatures begin to increase after the winter freeze early in April, but the graph is not detailed to discern the exact date in 1998. Because we do have data that can be viewed at more closely spaced intervals, we are able to "zoom" in on April and determine the date when soil temperatures do increase (Figure 7). From Figure 7 we are able to determine that the temperatures begin to increase on April 10.

Figure 8 shows a soil temperature pattern for 1998 that is very similar to Figure 6. For annual patterns, it appears that the "manual" data provide results that are nearly as useful as those from the "automated" data. The 1998 "manual" data were simulated by the same technique used for data from Table 4.

Figures 9 and 10 represent additional examples of soil moisture data that cannot be produced with confidence from the widely spaced "manual" data points. Figure 9 shows soil temperatures with depth from a site where there were temperature sensors at every depth. These data show the soil temperature gradient with depth in both summer and winter months. We recommend placing soil temperature sensors at more depths that was done in the early installations of this project. Figure 10 relates air and soil temperatures throughout the year from a Forest County site.



Conclusions

- The cost for automating data collection seems justified, especially when considered as a cost-per-data unit.
- A primary advantage of the "automated" data is the flexibility to interpret it at more levels of detail, i.e., every two hours, daily, monthly, annually, or other intervals. Conversely, the most detailed summary of the "manual" data is monthly, and that level of generalization has low confidence because it is based on a maximum of three data points in this project.
- Effects of soil morphology on the soil moisture patterns throughout the year are clearer from the "automated" data.
- The data "manual" and "automated" were comparable for most annual temperature averages and data patterns.
- "Automated" data are subject to fewer errors because of possible recording errors to the field sheets when sensors are read in the field and when the data are transferred from the field sheets to electronic storage.



Photo 1. Installations for Manual Sensor Readings



Photo 3. "Automated" Site Showing Datalogger Enclosure



Photo 2. Manual Sensor Readings with Meter



Photo 4. Data Retrieval with Laptop Computer

Figure 7. Detailed April Temperatures -- "Automated"

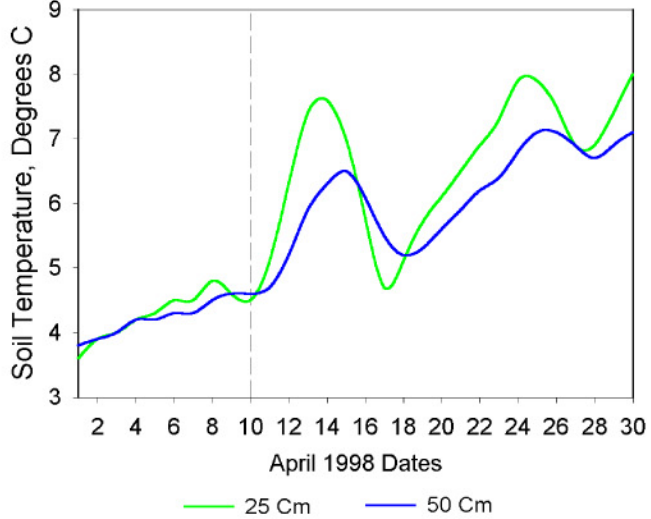


Figure 8. Annual Soil Temperature Pattern -- "Manual"

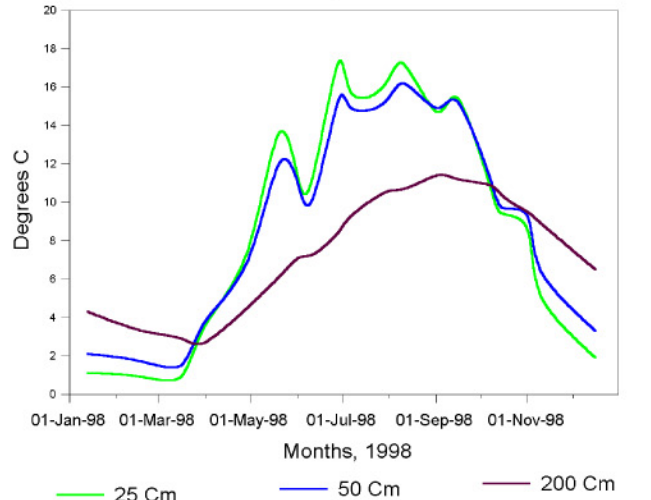


Figure 9. Seasonal Soil Temperature Changes with Depth -- "Automated"

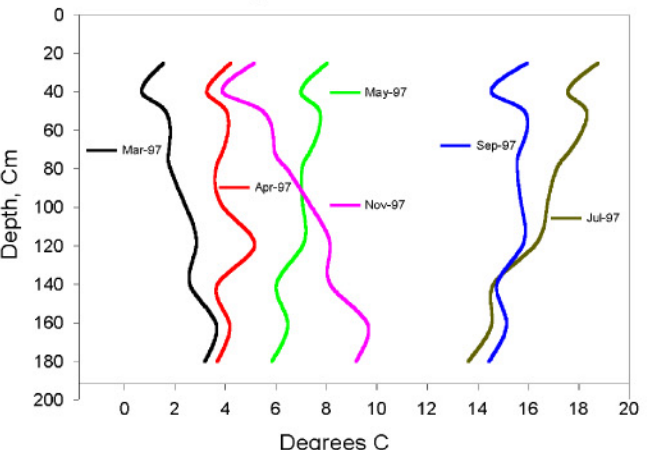


Figure 6. Annual Soil Temperature Pattern -- "Automated"

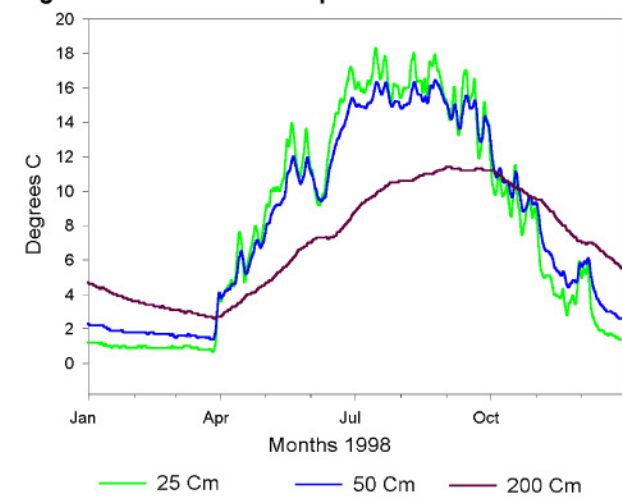


Figure 10. Generalized Air Temperature and Soil Temperature Relationships -- "Automated"

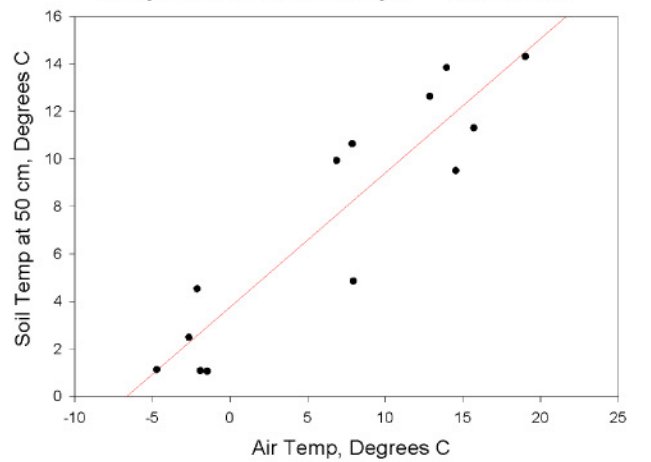


Table 1. Annual Site Costs With and Without Dataloggers

Source	Without Dataloggers (Dollars)	With Dataloggers (Dollars)
Equipment ¹	250	670
Equipment Preparation ¹	20	10
Installation ¹	70	320
Data Retrieval ¹	500	25
Annual Maintenance	100	200
Total	940	1225

¹ Amortized over the 10-year project life

Table 2. Cost Per Reading -- With and Without Dataloggers

	Without Dataloggers	With Dataloggers
Readings per year ²	900	64,800
Cost per reading	96 cents	1.9 cents

² Soil moisture and temperature readings only

Table 3. Locations Source of Figures and Tables

Graphic/Table	County	Site	Graphic/Table	County	Site
Figure 2	Forest	204	Figure 6	Lincoln	504
Figure 3	Forest	205	Figure 7	Lincoln	504
Figure 4	Forest	205	Figure 8	Lincoln	504
Figure 5	Forest	205	Figure 9	Clark	004
Table 4	Lincoln	504	Figure 10	Forest	201

Table 4. Soil Temperature Averages -- "Automated" vs. "Manual"

Depth cm	Mean Annual Automated	Mean Annual Manual	Mean Winter Automated	Mean Winter Manual	Mean Summer Automated	Mean Summer Manual
25	8.2	9.6	1.5	1.3	15.4	14.8
50	8.2	9.5	2.5	2.4	14.3	13.8
200	7.0	7.7	4.6	4.7	9.4	8.9

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